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1 Introduction

Volumetric capnography is an important tool to evaluate the quality and quantity of ventilation. CO2 monitoring data is helpful for the assessment of a patient’s airway integrity and to ensure proper endotracheal tube placement, among other applications.

Volumetric capnography measurements that are monitored by the ventilator include:

- CO2 elimination (V'CO2)
- End-tidal partial pressure CO2 (PetCO2 and FetCO2)
- Airway dead space (VDaw)
- Alveolar minute ventilation (V'alv)
- Capnogram shape (slopeCO2)

These parameters are described in further detail in this User Guide.

Additional information about volumetric capnography can be found on MyHamilton.

2 CO2 elimination (V'CO2)

CO2 elimination (V'CO2) is the net exhaled volume of CO2 in milliliters per minute (ml/min). V'CO2 measurements permit assessment of metabolic rate (for example, V'CO2 is high with sepsis and fever) and treatment progress.

V'CO2 is obtained by adding together V'CO2 measurements over several breaths and dividing the sum by the total time in minutes (Noe 1963). Steady-state conditions are essential to interpret the V'CO2 values (Brandi 1999). V'CO2 represents CO2 elimination but not necessarily CO2 production. Normal values for V'CO2 are provided in Table 1.

To convert a time-based capnogram into a volumetric capnogram, CO2 must be combined with flow.

By combining the FetCO2/time graph (Figure 1) with the Flow/time graph (Figure 2), you can derive the volume of CO2 exhaled in one breath (Figure 3).

The area under the expiratory waveform minus the area under the inspiratory waveform is the net transfer of CO2 out of the lungs per breath, or V'CO2.

Figure 1. Typical capnogram of patient on pressure-controlled ventilation, showing FCO2/time

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1 Inspiration starts at time 0; exhalation starts at approximately 2.75 seconds. Note that inspiratory gas initially contains CO2 (rebreathing) from artificial deadspace.
End-tidal CO2 (PetCO2 and FetCO2)

3 End-tidal CO2 (PetCO2 and FetCO2)

End-tidal CO2 is the maximum partial pressure of CO2 exhaled during a tidal breath, measured just before the start of inspiration. It represents the final portion of air that was involved in the exchange of gases in the alveolar area, thus providing a reliable index of CO2 partial pressure in the arterial blood under certain circumstances.

End-tidal CO2 is either measured as a partial pressure (PetCO2) or as a fractional concentration of CO2 in dry gas (FetCO2).

Normal values for PetCO2 and FetCO2 are provided in Table 1.

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2 The flow to the patient (inspiration) is negative, while the flow from the patient (exhalation) is positive. The expiratory flow waveform is an exponential decay curve. Note that in spontaneously breathing subjects, the flow waveforms may be different shapes.

3 ViCO2 is the volume of inspired CO2, while VeCO2 is the volume of exhaled CO2. The net elimination of CO2 is VeCO2 – ViCO2. ViCO2, a negative volume indicating rebreathed CO2, is normally omitted.
Airway dead space (VDaw)

**NOTICE**

The airway dead space (VDaw) is an approximation of the anatomical dead space.

The airway dead space (VDaw) measurement provides an effective in-vivo measure of volume lost in the conducting airways. A relative increase in dead space points to a rise in respiratory insufficiency and can be regarded as an indicator of the patient's current condition.

By dividing the capnogram into phases (Figure 4), VDaw can be calculated as the smallest measurable dead space, which is essentially the volume exhaled in Phase I.

The calculation, described by Wolff 1989 and Aström 2000, comprises a number of computational steps that take the slope of the alveolar plateau into account.

Normal values for VDaw are provided in Table 1.

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Alveolar minute ventilation (V’alv)

Alveolar minute ventilation (V’alv) permits assessment of actual alveolar ventilation (as opposed to minute ventilation). V’alv is defined as the difference between minute ventilation and V’Daw (airway dead space).

Not all gas that enters the alveoli participates in gas exchange. Some gas ends up in non- or under-perfused lung spaces. To measure the efficiency of alveolar ventilation, PaCO2 must be determined from an arterial blood gas sample. The ratio of mixed-to-ideal alveolar partial pressure is a measure of alveolar efficiency (Severinghaus 1957).

Normal values for V’alv are provided in Table 1.

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Capnogram shape (slopeCO2)

The slope of the alveolar plateau (slopeCO2) is defined by the PetCO2 capnogram shape and can indicate the volume/flow status of the lungs. The slopeCO2 value allows for the assessment of chronic hypercapnia, asthma, and inefficient ventilation. A steep slope is observed in COPD patients, while a flat plateau is seen in postoperative patients.

Normal values for slopeCO2 are provided in Table 1.

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4 Phase I: Pure airway dead space, from the point of measurement of CO2 toward the lungs.
Phase II: Weighted average of alveolar gas from different lung spaces, at the sensor location; measurement is VDaw.
Phase III: Alveolar plateau; the measurement is slopeCO2 plus end-tidal CO2, PetCO2, or FetCO2.
Table 1. Examples of normal or expected values in mechanically ventilated patients

<table>
<thead>
<tr>
<th>Description</th>
<th>Unit</th>
<th>Normal</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>VDaw</td>
<td>ml BTPS</td>
<td>2.2 ml/kg IBW</td>
<td>Radford 1954</td>
</tr>
<tr>
<td>slopeCO2</td>
<td>%CO2/l</td>
<td>31324 * Vt - 1.535</td>
<td>Aström 2000</td>
</tr>
<tr>
<td>V’CO2</td>
<td>ml/min STPD</td>
<td>2.6 to 2.9 ml/min/kg</td>
<td>Weissmann 1986, Wolff 1986</td>
</tr>
<tr>
<td>FetCO2(^6)</td>
<td>%</td>
<td>5.1 to 6.1%</td>
<td>Wolff 1986</td>
</tr>
<tr>
<td>PetCO2</td>
<td>mmHg</td>
<td>32 to 42 mmHg</td>
<td><a href="http://www.oem.respironics.com">www.oem.respironics.com</a></td>
</tr>
<tr>
<td>V’alv</td>
<td>mmHg</td>
<td>36 mmHg</td>
<td>Kiiski, Takala 1994(^7)</td>
</tr>
</tbody>
</table>

7 Formulas

Alveolar tidal ventilation (Vtalv)

\[ V_{talv} = V_t - VDaw \]

Alveolar minute ventilation (V’alv)

\[ V’_{alv} = f * V_{talv} \]

Volume of CO2 eliminated in one breath (V’CO2)

\[ V’_{CO2} = V_eCO2 - V_iCO2 \]

Fractional concentration of CO2 in exhaled gas (FetCO2)

\[ FetCO2 = V’_{CO2}/MinVol \]

Partial pressure of CO2 in exhaled gas (PetCO2)

\[ PetCO2 = FeCO2 * (P_b - PH2O) \]

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\(^5\) These values are for illustration purposes and do not replace physician-directed treatment.

\(^6\) Bulk gas volumes, such as minute ventilation and tidal volume, are usually measured in BTPS. Specific gas volumes are expressed in STPD. Conversion factors can be found in physics textbooks.

\(^7\) V’CO2 = V’alv * FetCO2

\(^8\) FetCO2 = PetCO2/(P_b – PH2O)
8 References


